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- (71) Applicant: 3M INNOVATIVE PROPERTIES COMPANY [US/US]; 3M Center, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).
- (72) Inventor: MOREN, Dean, M.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US).
- (74) Agents: MCGEEHAN, Lisa, M. et al.; Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).
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(54) Title: INITIATOR/HYDROXIDE AND INITIATOR/ALKOXIDE COMPLEXES, SYSTEMS COMPRISING THE COMPLEXES, AND POLYMERIZED COMPOSITIONS MADE THEREWITH

(57) Abstract: Initiator systems of the invention comprise: a complexed initiator comprising at least one of a complex of a complexing agent comprising at least one hydroxide and an initiator or a complex of a complexing agent comprising at least one alkoxide and an initiator; and a decomplexer. The initiator systems are useful for initiating polymerization of at least one monomer to form polymerized compositions. Kits of the invention useful for forming the polymerized compositions comprise a polymerizable composition and an initiator component, wherein the initiator component comprises a complexed initiator of the invention. Bonding compositions can be prepared by mixing the polymerizable composition of the kit with the respective initiator component.

**INITIATOR/HYDROXIDE AND INITIATOR/ALKOXIDE COMPLEXES,
SYSTEMS COMPRISING THE COMPLEXES, AND POLYMERIZED
COMPOSITIONS MADE THEREWITH**

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Field of the Invention

The present invention relates generally to complexes of initiators and complexing agents comprising at least one hydroxide, alkoxide, or mixtures thereof. The complexes are useful in initiator systems for polymerization of monomers.

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Background of the Invention

Systems for initiating the polymerization of monomers to make compositions, such as adhesives, are known in the art. U.S. Patent Nos. 5,106,928, 5,286,821, and 5,310,835 to Skoultchi et al., for example, describe two-part initiator systems for initiating the polymerization of acrylic monomers. The first part of these two-part systems typically includes a stable organoborane amine complex and the second part includes an activator. The activator liberates the organoborane compound by removing the amine group, thereby allowing the organoborane compound to initiate the polymerization process. Activators are also sometimes referred to as liberators or decomplexers.

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Common complexes in such systems include complexes of an organoborane and an amine. While such complexes may be useful in many applications, certain problems may arise due to the use of amine complexing agents in such conventional complexes. For example, when the complexes contain a primary amine, adhesives prepared therefrom may be prone to discoloration, such as yellowing. Furthermore, when including reactive diluents, such as aziridine-functional materials described in PCT Publication No. WO 98/17,694, for example, in compositions containing the complexes, the diluents may prematurely react with protic amines (i.e., those amines in which a nitrogen atom is bonded to at least one hydrogen atom) in such complexes, prematurely decomplexing the organoborane initiator. This phenomenon may even be to such an extent as to prematurely initiate polymerization of monomers present with the complexes or to degrade efficacy of the initiators for polymerization of subsequently added monomers.

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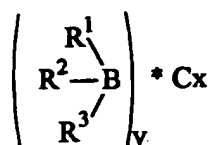
In light of these potential problems and the desire to provide alternative formulations, further complexes are desirable, particularly for use in initiator systems, such as those used for polymerization of adhesives useful for bonding low surface energy substrates.

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Summary of the Invention

Initiator systems of the invention comprise: a complexed initiator comprising at least one of a complex of a complexing agent comprising at least one hydroxide and an initiator and a complex of a complexing agent comprising at least one
10 alkoxide and an initiator; and a decomplexer. Preferably, the initiator comprises an organometallic initiator, such as an organoborane initiator.

Complexes of organoborane initiators and complexing agents of the invention may be represented by the following general Formula (I):



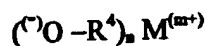
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(I)

wherein R^1 is an alkyl group having 1 to about 10 carbon atoms. R^2 and R^3 may be the same or different and are selected from (i.e., they are independently selected from) alkyl groups having 1 to about 10 carbon atoms and phenyl-containing groups. "Cx" represents a complexing agent of the invention. The value of "v" is
20 selected so as to provide an effective ratio of oxygen atoms of the alkoxides and/or hydroxides to boron atoms in the complex.

The initiator systems are useful for initiating polymerization of at least one monomer. To initiate polymerization in such a manner, at least one monomer is provided and then blended with the initiator system. Polymerization of the at least
25 one monomer can be initiated as such.

In one embodiment, the complexed initiator comprises a complexing agent represented by Formula (II):



(II)

wherein each R^4 is independently selected from hydrogen or an organic group (e.g., an alkyl or alkylene group); $M^{(m+)}$ represents a countercation (comprising a monovalent cation, such as a Group IA metal (e.g., sodium and potassium) cation or onium, or a multivalent cation, such as a Group IIA metal (e.g., calcium and magnesium) cation); n is an integer greater than zero; and m is an integer greater than zero. Preferably, n and m are equal. Preferably, each R^4 is the same in a complexing agent. Particularly preferred complexing agents comprise those having a countercation comprising a cation selected from sodium, potassium, and tetraalkylammoniums.

According to another aspect of the invention, complexing agents of the invention are used as part of a kit. In one embodiment, kits of the invention comprise a polymerizable composition, wherein the polymerizable composition comprises:

- at least one polymerizable monomer, and
- at least one decomplexer; and
- an initiator component, wherein the initiator component comprises:
 - a complexed initiator comprising at least one of:
 - a complex of a complexing agent comprising at least one hydroxide and an initiator, and
 - a complex of a complexing agent comprising at least one alkoxide and an initiator, and
 - an optional diluent.

A bonding composition can be prepared by mixing the polymerizable composition of the kit with the respective initiator component. The bonding composition can be used, for example, to prepare substrates at least partially coated with the bonding composition and bonded articles comprising a first substrate and a second substrate, with the polymerized bonding composition adhesively bonding the first and second substrates together. The bonding compositions are particularly useful for coating low surface energy substrates.

Detailed Description of the Preferred Embodiments

This invention provides initiator systems capable of initiating polymerization. More specifically, the invention provides "initiator systems" comprising (1) a complexed initiator (for example, an organoborane hydroxide, an organoborane alkoxide complex, or mixtures or combinations thereof) and (2) a decomplexer.

In one aspect of the invention, the initiator system is part of a multi-part kit. Such kits comprise at least a first part (i.e., a polymerizable composition) and a second part (i.e., an initiator component) for initiating polymerization of the polymerizable composition. Most preferably, for ease of use, the kits comprise only two parts. The two parts of the kit may be readily combined in a convenient, commercially useful, whole number mix ratio of 1:10 or less, more preferably 1:4, 1:3, 1:2 or 1:1, such that they can be easily used with multi-part dispensers. Such dispensers are shown in U.S. Patent Numbers 4,538,920 and 5,082,147 and are available from ConProTec, Inc. (Salem, NH) under the trade designation, MIXPAC. The parts of the kit can be readily mixed to form bonding compositions, which readily polymerize to polymers, for example, adhesives.

The "polymerizable composition" typically comprises at least one decomplexer and at least one polymerizable monomer.

The "initiator component" typically comprises at least one complexed initiator (e.g., an organoborane hydroxide complex, an organoborane alkoxide complex, or mixtures or combinations thereof) and an optional diluent. When mixed with the polymerizable composition, the decomplexer in the polymerizable composition liberates the initiator (e.g., organoborane) from the complexing agent (e.g., a complexing agent comprising at least one hydroxide, alkoxide, or mixtures thereof), enabling polymerization of the monomer(s) to be initiated.

"Bonding compositions" are those compositions resulting from mixing of the polymerizable composition and the initiator component according to one aspect of the invention. The bonding compositions are useful for bonding a wide variety of substrates, including substrates derived from polymers, wood, ceramics, concrete,

and metals. The bonding compositions are especially useful for bonding low-surface energy substrates.

“Low surface energy substrates” are those that have a surface energy of less than 45 mJ/m^2 , more typically less than 40 mJ/m^2 or less than 35 mJ/m^2 . Included among such materials are, for example, polyethylene and polypropylene.

Other polymers of higher surface energy that may also be usefully bonded with the compositions of the invention include polycarbonate and polymethylmethacrylate. However, the invention is not so limited; the compositions may be used to bond any suitable substrate, such as those derived from thermoplastics, as well as wood, ceramics, concrete, primed metals, and the like.

“Polymerized compositions” (also referred to as polymers) are those compositions where substantially all of the monomers in the bonding composition are polymerized except for a typically unpolymerized amount as recognizable to one of ordinary skill in the art. Polymerized compositions according to the invention may be used in a wide variety of ways, including, for example, as adhesives, bonding materials, sealants, coatings, and injection molding resins. The polymerized compositions may also be used as matrix resins in conjunction with glass, carbon, and metal fiber mats, such as those used in resin transfer molding operations. The polymerized compositions may further be used as encapsulants and potting compounds, such as in the manufacture of electrical components, printed circuit boards, and the like. Those of ordinary skill in the art will recognize a wide variety of other applications in which the polymerized compositions are useful.

Initiator Component

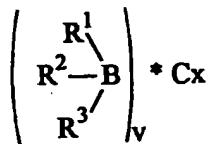
Complexed Initiator

In general, complexed initiators of the invention are complexes of an initiator and a complexing agent, specifically complexing agent comprising at least one hydroxide, alkoxide, or mixtures thereof. A “complex” is readily understood by one of ordinary skill in the art to be a tightly coordinated salt formed by association of a Lewis acid (e.g., initiator) and a Lewis base (e.g., hydroxide or alkoxide).

Any suitable complexing agent comprising at least one hydroxide, alkoxide, or mixtures or combinations thereof, may be used for the complexing agent, as long as the complexing agent is reactive with the decomplexer (if any) with which it is to be used. Furthermore, the complexing agent should also be capable of forming a
 5 complex with the initiator with which it is used.

Any suitable initiator, or combinations thereof, may be used in the invention, as long as the initiator is capable of forming a complex with the complexing agent. Furthermore, the initiator should also be capable of initiating polymerization of monomers with which it is to be used. Preferably, the initiator is an organometallic
 10 initiator.

According to one aspect of the invention, the initiator is as an organoborane. Complexes of organoborane initiators and complexing agents of the invention may be represented by the following general Formula (I):



(I)

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wherein R^1 is an alkyl group having 1 to about 10 carbon atoms. R^2 and R^3 may be the same or different and are selected from (i.e., they are independently selected from) alkyl groups having 1 to about 10 carbon atoms and phenyl-containing groups. Preferably, R^1 , R^2 and R^3 are independently selected from alkyl groups
 20 having 1 to about 5 carbon atoms. Accordingly, R^1 , R^2 and R^3 may all be different, or more than one of R^1 , R^2 and R^3 may be the same. Most preferably, R^1 , R^2 and R^3 are the same.

Together, R^1 , R^2 and R^3 , along with the boron atom (B) to which they are attached, form the initiator. Specific organoborane initiators include, for example,
 25 trimethylborane, triethylborane, tri-n-propylborane, triisopropylborane, tri-n-butylborane, triisobutylborane, and tri-sec-butylborane.

"Cx" in Formula I represents a complexing agent of the invention, which is described further below.

The value of "v" is selected so as to provide an effective ratio of oxygen atoms of the alkoxides and/or hydroxides to boron atoms in the complex. The ratio of oxygen atoms of the alkoxides and/or hydroxides to boron atoms in the complex should broadly be about 0.5:1 to about 4:1, preferably about 1:1 to about 2:1, more preferably about 1:1 to about 1.5:1, and most preferably about 1:1.

Complexing Agent

The following terms will hereinafter be used to more particularly describe the complexing agent of the invention:

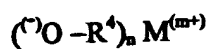
The terms "monovalent organic group" and "multivalent organic group" mean an organic moiety wherein the available valencies are on carbon atoms. Monovalent organic groups have one available valency. Accordingly, multivalent organic groups have more than one available valency.

The "organic groups" can be aliphatic groups or cyclic groups. In the context of the present invention, the term "aliphatic group" means a saturated or unsaturated, linear or branched, hydrocarbon group. This term is used to encompass alkylene, alkenylene, alkynylene, alkyl, alkenyl, and alkynyl groups, for example. The term "alkyl group" means a monovalent, saturated, linear or branched, hydrocarbon group (e.g., a methyl, ethyl, isopropyl, t-butyl, heptyl, dodecyl, octadecyl, amyl, or 2-ethylhexyl group, and the like). The term "alkylene" means a multivalent, saturated, linear or branched hydrocarbon group. The term "alkenyl group" means a monovalent, unsaturated, linear or branched, hydrocarbon group with one or more carbon-carbon double bonds (e.g., a vinyl group). The term "alkenylene" means a multivalent, unsaturated, linear or branched, hydrocarbon group with one or more carbon-carbon double bonds. The term "alkynyl group" means a monovalent, unsaturated, linear or branched, hydrocarbon group with one or more carbon-carbon triple bonds. The term "alkynylene" means a multivalent, linear or branched, hydrocarbon group with one or more carbon-carbon triple bonds.

The term "cyclic group" or "cyclic structure" means a closed ring hydrocarbon group that is classified as an alicyclic group, aromatic group, or heterocyclic group. The term "alicyclic group" means a cyclic hydrocarbon group having properties resembling those of aliphatic groups. The term "aromatic group" or "aryl group" means a mononuclear aromatic hydrocarbon group or polynuclear aromatic hydrocarbon group.

Organic groups or organic linking groups, as used herein, can include internal (i.e., not terminal) heteroatoms (e.g., O, N, or S atoms), such as in the case of heterocyclic groups, as well as internal functional groups (e.g., carbonyl groups).

Cx in Formula (I) represents a complexing agent comprising at least one hydroxide, alkoxide, or mixtures thereof. Preferably, Cx and complexing agents of the invention are represented by the following Formula (II):



(II)

Each R⁴ is independently selected from hydrogen or an organic group and each of n and m are integers greater than zero.

Each R⁴ may be hydrogen in a complexing agent or each R⁴ may be an organic group in a complexing agent. When any R⁴ is hydrogen, the complexing agent is said to comprise at least one hydroxide. When any R⁴ is an organic group, the complexing agent is said to comprise at least one alkoxide. Preferred alkoxides are those where R⁴ is an alkyl group or an alkylene group. The complexing agent may also include a mixture of at least one hydroxide and at least one alkoxide.

Typically, n is 1 or 2 and m is 1 or 2. Preferably, n and m are the same integer, most preferably 1.

In general, the complexing agent is used in the form of a salt. That is, the complexing agent is stabilized by a suitable counteraction such that the complexing agent is capable of complexing the initiator. Thus, in Formula II, M^(m+) represents a counteraction that stabilizes the complexing agent.

Any suitable cation or combinations thereof can be used for counteractions of the invention. The cations can be monovalent or multivalent, as indicated by the

superscript, "m+." When "m+" is 1, the cation is monovalent. For example, monovalent cations of the Group IA metals (e.g., lithium, sodium, and potassium) can be used. Other suitable monovalent cations include oniums, which generally conform to the following Formula (III):



Each R^5 is independently selected from monovalent organic groups. Accordingly, each R^5 in Formula III may be different, or more than one R^5 may be the same. In Formula III, z represents an integer greater than one. Typically z is 2, 3, or 4. Typically, X is a Group VA, VIA, or VIIA metalloid (e.g., nitrogen, sulfur, iodine, and phosphorus). Exemplary onium cations include tetraalkylammoniums (e.g., tetramethylammonium and tetrabutylammonium), triphenylsulfonium, diphenyliodonium, and tetrabutylphosphonium.

10

When "m+" is greater than 1, the cation is multivalent. Exemplary multivalent cations include those cations of the Group IIA metals (e.g., calcium and magnesium).

15

Monovalent cations are preferred. Especially preferred are sodium, potassium, and tetraalkylammoniums.

Certain complexes comprising hydroxides are known in the art. For example, see certain of the chemical structures disclosed in Brown, Herbert C., Hydroboranes, pp. 55-56 (1962). However, the use of such complexes in initiator systems of the invention has not been reported.

20

Hydroxides and alkoxides provide strong coupling to organometallic initiators, such as organoboranes, with the resulting complexes having excellent oxidative stability. Thus, the use of complexing agents comprising at least one hydroxide, alkoxide, or mixtures thereof is particularly beneficial, particularly in initiator systems of the invention.

25

Advantageously, preferred complexes of the invention are air stable. By "air stable" it is meant that, when the complexes are stored in a capped vessel at room temperature (about 20° to about 22°C) and under otherwise ambient conditions (i.e., not under a vacuum and not in an inert atmosphere), the complexes remain

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useful as polymerization initiators for at least about two weeks. Preferably, the complexes may be readily stored under these conditions for many months and up to a year or more.

Air stability of the complex is enhanced when the complex is a crystalline material (i.e., the complex is a solid at room temperature, but has a measurable melting point when measured according to Differential Scanning Calorimetry). However, complexes of the invention are air stable for at least six months even when they are liquids at room temperature. In some embodiments, liquid complexes (i.e., those complexes having a measurable melting point that is lower than room temperature when measured according to Differential Scanning Calorimetry) and solutions of liquid or solid complexes may be preferred because liquids are generally easier to handle and mix at room temperature than are solids. One of ordinary skill in the art is capable of readily determining whether a complex based on selected initiators and complexing agents is a liquid or solid at room temperature.

Particularly preferred "air stable" complexes are non-pyrophoric. That is, the complexes do not spontaneously combust or self-ignite. One of ordinary skill in the art is capable of readily determining whether a complex based on selected initiators and complexing agents is non-pyrophoric. For example, the Pyrophoricity Test described in the Examples, infra, is one method of determining whether a complex is pyrophoric.

Exemplary complexing agents useful in the preparation of complexes of the invention include those prepared from the following: sodium hydroxide, tetrabutylammonium hydroxide, sodium methoxide, and tetrabutylammonium methoxide. Exemplary organoboranes useful in the preparation of complexes of the invention include: triethylborane and tributylborane. It should also be noted that blends of different complexes may be used in initiator systems of the invention.

Complexes of the invention may be readily prepared using known techniques. Typically, the complexing agent is combined with the initiator in an inert atmosphere with slow stirring. An exotherm is often observed and cooling of

the mixture is therefore recommended. If the ingredients have a high vapor pressure, it is desirable to keep the reaction temperature below about 70°C. to 80°C. Once the materials have been well mixed, the complex is permitted to cool to room temperature (i.e., about 22°C. to about 25°C.). No special storage conditions are required although it is preferred that the complex be kept in a capped vessel in a cool, dark location. Advantageously, the complexes can be prepared in the absence of organic solvents that would later have to be removed, although they could be prepared in solvent if so desired.

The resulting complex is employed in an effective amount, which is an amount large enough to permit polymerization to readily occur to obtain a polymer (preferably, an acrylic polymer). According to one aspect of the invention, when the initiator comprises an organoborane, an effective amount of the organoborane complex is an amount that provides about 0.01 weight % boron to about 1.5 weight % boron, more preferably about 0.01 weight % boron to about 0.60 weight % boron, most preferably about 0.02 weight % boron to about 0.50 weight % boron, based on the total weight of the bonding composition, less the weight of fillers, non-reactive diluents, and other non-reactive components. If the amount of organoborane complex is too low, resulting polymerization may be incomplete or, in the case of adhesives, the resulting composition may have poor adhesion.

On the other hand, if the amount of organoborane complex is too high, then polymerization may proceed too rapidly to allow for effective mixing and use of the resulting composition. Large amounts of the complex could also lead to the generation of large volumes of borane, which in the case of an adhesive, may weaken the bondline when used for bonding substrate(s). The useful rate of polymerization will depend in part on the method of applying the composition to a substrate. Thus, a faster rate of polymerization may be accommodated by using a high-speed, automated industrial adhesive applicator rather than by applying the composition with a hand applicator or by manually mixing the composition.


30 Diluent

The initiator component may also contain any suitable diluent, or combination thereof. The diluent may be reactive or nonreactive with monomers used in the polymerizable composition.

Preferably, the diluent is inert toward the complexing agent. That is, preferably the diluent is essentially free of moieties that are reactive with the complexing agent (i.e., moieties that are susceptible to being esterified by or hydrolyzed by the complexing agent) such that the complexing agent is incapable of complexing the initiator or such that the diluent is chemically modified in such a way that desired properties of the composition are affected.

Nonreactive diluents include plasticizers well known to those of ordinary skill in the art. Reactive diluents include, for example, aziridine-functional materials and maleate-functional materials. For example, such reactive diluents are described in PCT Publication No. WO 98/17,694 and U.S. Application Serial No. 09/272,152, entitled "Organoborane Amine Complex Initiator Systems and Polymerizable Compositions Made Therewith, assigned to the assignee of the present invention with Attorney Docket No. 54677USA7A.

An "aziridine-functional material" refers to an organic compound having at

least one aziridine ring or group, , the carbon atom(s) of which may optionally be substituted by short chain alkyl groups (e.g., groups having 1 to about 10 carbon atoms, preferably methyl, ethyl or propyl), so as to form, for example, methyl, ethyl or propyl aziridine moieties.

Examples of useful, commercially available polyaziridines include those available under the following trade designations: **CROSSLINKER CX-100** (from Zeneca Resins; Wilmington, MA), **XAMA-2** (from EIT, Inc.; Lake Wylie, SC), **XAMA-7** (from EIT, Inc.; Lake Wylie, SC), and **MAPO** (tris [1-(2-methyl) aziridinyl] phosphine oxide (from Aceto Chemical Corporation; Flushing, NY).

Quite advantageously, when used, the complex is carried by (e.g., dissolved in or diluted by) the diluent or a blend of two or more different diluents in the initiator component. Generally, the diluent should not be reactive toward the complex and functions as an extender for the complex. Also advantageously, the

diluent may generally increase the spontaneous combustion temperature of the initiator component, increasing the non-pyrophoric characteristics of the initiator component.

5 The diluent should be generally soluble in monomers included in the polymerizable composition, such that the parts of the kit can be readily mixed. By "soluble" is meant that no evidence of gross phase separation at room temperature (i.e., about 22°C. to about 25°C.) is visible to the unaided eye. Similarly, the complex should also be soluble in the diluent, although slightly warming a mixture of the complex and the diluent may be helpful in forming a solution of the two at
10 room temperature (i.e., about 22°C. to about 25°C.). Accordingly, preferably, if used, the diluent is a liquid at or near room temperature (i.e., within about 10°C. of room temperature) or forms a liquid solution with the complex at or near room temperature.

The diluent is used in an effective amount. Generally, this is an amount of
15 not more than about 50 weight %, preferably not more than about 25 weight %, more preferably not more than about 10 weight %, based on the total weight of the bonding composition. However, substantial amounts (e.g., more than about 15 weight %, sometimes more than about 40 weight %) of the complex may be dissolved in the diluent, which facilitates the provision of multi-part kits that can be
20 combined in a commercially useful mix ratio.

Polymerizable Composition

Decomplexer

25 The term "decomplexer" means a compound capable of liberating the initiator (e.g., organoborane) from its complexing agent, thereby enabling initiation of the polymerization process. Decomplexers are also sometimes referred to as "activators" or "liberators." As used herein, each of these terms has the same meaning.

30 Any suitable decomplexer, or combinations thereof, can be used, such as isocyanates, acids, acid chlorides, sulfonyl chlorides, anhydrides, compounds capable of liberating any of the foregoing when combined with the initiator

component, and mixtures thereof. Examples of suitable acids include Lewis acids and Brønsted acids. Particularly suitable decomplexers include lower molecular weight carboxylic acid decomplexers described by Skoultchi et al. (U.S. Patent Nos. 5,310,835 and 5,106,928), sulfonyl chlorides and acid chlorides of Fujisawa, Imai, and Mashuhara (Reports of the Institute for Medical and Dental Engineering, vol. 3, p. 64 (1969)), bireactive decomplexers comprising isocyanate groups described by Deviny (PCT Publication No. WO97/07,171), anhydride decomplexers described by Deviny (PCT Publication No. WO97/17,383), carboxylic acid decomplexers described by Deviny et al. (PCT Application No. US98/12,296, filed June 12, 1998 and entitled "Initiator Systems and Adhesive Compositions Made Therewith"), and mixtures thereof. All of these publications are incorporated herein by reference.

The decomplexer is employed in an effective amount (i.e., an amount effective to promote polymerization by liberating the initiator from its complexing agent, but without materially adversely affecting desired properties of the ultimate polymerized composition). As recognizable to one of ordinary skill in the art, too much of the decomplexer may cause polymerization to proceed too quickly and, in the case of adhesives, the resulting materials may demonstrate inadequate adhesion to low energy surfaces. However, if too little decomplexer is used, the rate of polymerization may be too slow and the resulting polymers may not be of adequate molecular weight for certain applications. A reduced amount of decomplexer may be helpful in slowing the rate of polymerization if it is otherwise too fast. Thus, within these parameters, the decomplexer is typically provided in an amount such that the ratio of hydroxide- or alkoxide-reactive groups in the decomplexer(s) (e.g., acid groups or anhydride groups) to hydroxide and alkoxide groups in the complexing agent(s) is in the range of 0.5:1.0 to 3.0:1.0. For better performance, preferably the ratio of hydroxide- or alkoxide-reactive groups in the decomplexer(s) to hydroxide and alkoxide groups in the complexing agent(s) is in the range of 0.5:1.0 to 1.0:1.0, preferably about 1.0:1.0.

Monomers

The initiator system of the invention can be used to initiate the polymerization of any suitable monomer(s). Broadly, the polymerizable composition includes at least one ethylenically unsaturated monomer capable of free radical polymerization. Numerous compounds containing ethylenic unsaturation can be used in the polymerizable composition. Preferably, the composition includes at least one (meth)acrylic monomer, most preferably a methacrylic monomer. Particularly preferred are (meth)acrylic acid derivatives, such as those including esters and/or acid amides. Suitable are, for example, the (meth)acrylic esters of monohydric alcohols, particularly alkanols having from 1 to 12 carbon atoms, such as methyl (meth)acrylate, ethyl (meth)acrylate, butyl (meth)acrylate, and ethylhexyl (meth)acrylate; the (meth)acrylic acid esters of polyhydric alcohols, such as ethylene glycol, diethylene glycol, polyethylene glycol, and trimethylol propane; the di- and mono(meth)acrylic acid esters of glycerin; the di(meth)acrylic acid esters of triethylene glycol and tetraethylene glycol; the di(meth)acrylic acid esters of dipropylene glycol, tripropylene glycol, tetrapropylene glycol and pentapropylene glycol; and the di(meth)acrylic esters of ethoxylated or propoxylated diphenylolpropane.

Basically suitable are also polymerizable monomers, such as vinyl acetate; vinyl halides, such as vinyl chloride, vinyl fluoride, vinyl bromide; styrene; and divinyl-benzene. These compounds, however, are generally used only in subordinate amounts in the polymerizable compositions.

Further suitable are acid amides, such as: acrylamide; N-methyl acrylamide; N-methyl methacrylamide; N,N-dimethyl acrylamide; N,N-dimethyl methacrylamide; N-ethyl methacrylamide; N,N-diethyl acrylamide; N,N-diethyl methacrylamide; N-isopropyl acrylamide; N-butyl acrylamide; N-butyl methacrylamide; N-t-butyl acrylamide; N,N-dibutyl methacrylamide; N-phenyl acrylamide; N-(acryloyl)morpholine; N-(acryloyl)piperidine; N-(methacryloyl)piperidine; N-(1,1-dimethyl-3-oxobutyl)-acrylamide;

N-1,1,3,3-tetramethylbutyl acrylamide; dimethylene-bis-(meth)acrylamide; tetramethylene-bis-(meth)acrylamide; trimethylhexamethylene-bis-(meth)acrylamide; tri(meth)acryloyldiethylenetriamine; and similar compounds.

5 In general, the emphasis is on monomers with one or two olefinic double bonds in the molecule, preferably one olefinic double bond. The additional use of higher unsaturated components is not excluded, but it must be kept in mind that their presence can lead to embrittling of the polymerized compositions.

Additives

10 Bonding compositions of the present invention may also comprise further optional additives. Generally, such additives are present in the polymerizable composition of the kit. Thus, the polymerizable composition may further comprise a variety of optional additives.

15 One particularly useful additive is a thickener, such as medium (about 40,000) molecular weight polybutyl methacrylate that may generally be incorporated in an amount of up to about 50 weight %, based on the total weight of the polymerizable composition. Thickeners may be employed to increase the viscosity of the resulting bonding composition to a more easily applied viscous syrup-like consistency.

20 Another particularly useful additive is an elastomeric material. These materials can improve the fracture toughness of bonding compositions made therewith, which can be beneficial when, for example, bonding stiff, high yield strength materials (e.g., metal substrates that do not mechanically absorb energy as easily as other materials, such as flexible polymeric substrates). Such additives can generally be incorporated in an amount of up to about 50% by weight, based on the total weight of the polymerizable composition.

25 Core-shell polymers can also be added to the polymerizable composition to modify spreading and flow properties of the bonding composition. These enhanced properties may be manifested by a reduced tendency for the bonding composition to leave an undesirable "string" upon dispensing from a syringe-type applicator, or sag
30 r slump after having been applied to a vertical surface. Accordingly, use of more

than about 20% by weight, based on total weight of the polymerizable composition, of a core-shell polymer additive may be desirable for achieving improved sag-slump resistance. Core-shell polymers can also improve the fracture toughness of bonding compositions made therewith, which can be beneficial when, for example, bonding stiff, high yield strength materials (e.g., metal substrates that do not mechanically absorb energy as easily as other materials, such as flexible polymeric substrates).

Small amounts of inhibitors, such as hydroquinone monomethyl ether may be used in the polymerizable compositions, for example, to prevent or reduce degradation of the monomers during storage. Inhibitors may be added in an amount that does not materially affect the rate of polymerization or the ultimate properties of polymers made therewith. Accordingly, inhibitors are generally useful in amounts of about 100-10,000 ppm based on the total weight of the monomers in the polymerizable composition.

Other possible additives include non-reactive colorants, fillers (e.g., carbon black, hollow glass/ceramic beads, silica, titanium dioxide, solid glass/ceramic spheres, and chalk), and the like. The various optional additives are employed in any amount, but generally amounts that do not significantly adversely affect the polymerization process or the desired properties of polymers made therewith.

20 Bonding Compositions

The parts of the kits (i.e., the polymerizable composition and the initiator component) are blended as would normally be done when working with such materials. The initiator component is added to the polymerizable composition shortly before it is desired to use the bonding composition.

Once the parts of the kit have been combined to form a bonding composition, the composition should be used quickly, as the useful pot life may be short depending upon the monomers, the amount of the initiator component, the temperature at which the bonding is to be performed, the presence or absence of crosslinking agents, and whether a diluent is used. Preferably, to improve bonding, it is desirable to keep the initial bonding temperature below about 40°C., preferably

below 30°C., and most preferably below about 25°C. Accordingly, the bonding process can be carried out at room temperature (i.e., about 22°C. to about 25°C.).

5 The bonding composition is applied to one or both substrates to be bonded and then the substrates are joined together with pressure to force excess bonding composition out of the bond line. This also has the advantage of displacing bonding composition that has been exposed to air and that may have begun to oxidize. In general, the bonds should be made shortly after the bonding composition has been applied to the substrate(s), preferably within about 10 minutes. The typical bond line thickness is about 0.1 to 0.3 millimeters.

10 The bonds may cure (i.e., polymerize) to a reasonable green strength, i.e., to permit handling of such bonded articles within about 2-3 hours. Full bond strength will generally be reached in about 24 hours under ambient conditions. However, post-curing with heat may be used, if desired.

15 In one preferred embodiment, the bonding compositions are coated on a low surface energy substrate. In another preferred embodiment, bonded articles comprise a first substrate and a second substrate (preferably at least one of which is a low surface energy polymeric material) adhesively bonded together by a layer of a bonding composition according to the invention.

20 The invention will be more fully appreciated with reference to the following nonlimiting examples. These examples are merely for illustrative purposes only and are not meant to be limiting on the scope of the appended claims. All parts, percentages, ratios, etc. in the examples and the rest of the specification are by weight unless indicated otherwise.

Examples

Various tradenames and abbreviations used in the examples are defined according to the following schedule:

Abbreviation/Tradename	Description
BA	Butyl acrylate, available from Aldrich Chemical Company; Milwaukee, WI
BLENDIX 360	Trade designation for a core-shell toughener available from GE Specialty Chemicals; Parkersburg, WV
CAB-O-SIL TS 720	Trade designation for fumed silica available from Cabot Corporation; Tuscola, IL
CROSSLINKER CX-100 or CX-100	Trade designation for trimethylolpropane tris(3-(2-methylaziridino)propionate, commercially available from Zeneca Resins; Wilmington, MA
ELVACITE 2010	Trade designation for poly(methyl methacrylate) available from ICI Acrylics; Wilmington, DE
HDPE	High-density polyethylene, available from Cadillac Plastic; Minneapolis, MN
KOtBu	Potassium <i>tert</i> -butoxide, available from Aldrich Chemical Company; Milwaukee, WI
MAA	Methacrylic acid, available from Aldrich Chemical Company; Milwaukee, WI
MIXPAC SYSTEM 50	Trade designation for a 10:1 volume ratio dual syringe applicator, Kit No. MP-050-10-09, commercially available from ConProTec; Salem, NH
MMA	Methyl methacrylate, available from Aldrich Chemical Company; Milwaukee, WI
NaOH	Sodium hydroxide, available from Aldrich Chemical Company; Milwaukee, WI
NaOMe	Sodium methoxide, available from Aldrich Chemical Company; Milwaukee, WI
P25	Trade designation for titanium dioxide available from Degussa Corporation; Chester, PA
poly(MMA-co-EA)	poly(methyl methacrylate-co-ethyl acrylate), commercially available under catalog number 18224-9 from Aldrich Chemical Company; Milwaukee, WI.
PP	Polypropylene, available from Cadillac Plastic; Minneapolis, MN
PTFE	Polytetrafluoroethylene, available from Cadillac Plastic; Minneapolis, MN
TEB	Triethylborane, available from Aldrich Chemical Company; Milwaukee, WI
THF	Tetrahydrofuran, available from Aldrich Chemical Company; Milwaukee, WI

5

Overlap Shear Bond Strength Test

Each bonding composition was applied directly onto an untreated 2.5 cm x 10 cm x 0.3 cm (1 inch x 4 inch x 0.125 inch) test panel (0.2 millimeter (8 mil)-

diameter glass bead spacers were added to the bonding composition) and a bare second test panel was immediately placed against the bonding composition on the first test panel so that the overlapped area was 1.3 cm x 2.5 cm (0.5 inch x 1 inch). A clamp was applied to the overlapped area. The test panels were either

5 polytetrafluoroethylene (PTFE), high-density polyethylene (HDPE) or polypropylene (PP), as noted in the particular examples, all panels of which are commercially available from Cadillac Plastic; Minneapolis, MN. A small amount of bonding composition squeezed out of the overlapped area and was allowed to remain.

10 The bonds were allowed to cure for at least 48 hours at 22°C. The clamps were then removed, and the overlap bonds were tested in shear (OLS) on a tensile tester at a crosshead speed of 1.27 cm/minute (0.5 inch/minute). The overlap shear values were recorded in pounds and converted into pounds per square inch (psi) and megaPascals (MPa).

15 Preferably, for adequate bonding performance, the OLS values were at least about 150 psi (1.03 MPa), more preferably at least about 300 psi (4.14 MPa) for the PTFE; at least about 500 psi (3.45 MPa), more preferably at least about 700 psi (4.83 MPa) for the HDPE; and at least about 600 psi (4.14 MPa), more preferably at least about 800 psi (5.52 MPa) for the PP. Also, for diverse utility, it is

20 preferable that a particular adhesive is able to adequately bond at least two different types of low surface energy substrates. Accordingly, more preferably, a particular adhesive is able to adequately bond all of PTFE, HDPE, and PP. Most preferably, a particular adhesive is able to adequately bond PTFE to an OLS value of at least

25 about 300 psi (4.14 MPa), HDPE to an OLS value of at least about 700 psi (4.83 MPa), and PP to an OLS value of at least about 800 psi (5.52 MPa).

Organoborane Complex PreparationExamples 1-3

Sodium hydroxide, sodium methoxide, and potassium *tert*-butoxide complexes with triethylborane were prepared by combining equimolar quantities of a complexing agent with triethylborane under a nitrogen atmosphere without external temperature control. The complexes were prepared as aqueous, methanolic, and tetrahydrofuran solutions, respectively. Aqueous sodium hydroxide and triethylborane formed separate phases initially, becoming homogeneous after several hours of mixing at room temperature. The quantities of each component and type of complexing agent are noted in Table 1.

Table 1

Ex.	Complexing Agent (weight % in solution)	Weight Complexing Agent (grams (millimoles)) [weight of solution - grams]	Weight Triethylborane (grams (millimoles))
1	Sodium hydroxide (50% in water)	0.40 (10) [0.80]	0.98 (10)
2	Sodium methoxide (25% in methanol)	0.54 (10) [2.16]	0.98 (10)
3	Potassium <i>tert</i> - butoxide (36 % in THF)	1.12 (10) [3.12]	0.98 (10)

15 Pyrophoricity Test:

The pyrophoricity of each organoborane complex (Example 1-3) was tested by applying a 0.05 ml aliquot to a 1"x1" paper towel fragment in air to produce a treated paper towel. If the treated paper towel self-ignited (i.e., spontaneously combusted) within one minute or less, the composition is considered pyrophoric. If the treated paper towel did not self-ignite after ten minutes, the composition is considered non-pyrophoric. Results of whether or not each composition is pyrophoric according to the above-described test are tabulated in Table 2.

Table 2

Ex.	Complexing Agent	Pyrophoric?
1	NaOH	No
2	NaOMe	No
3	KOtBu	No

¹H-NMR Spectroscopy (Proton Nuclear Magnetic Resonance Spectroscopy)

5 ¹H-NMR chemical shift in CDCl₃ of methylene groups adjacent to boron in sodium methoxide triethylborane complexes further demonstrated the strong coupling of organoborane complexes useful in the invention. ¹H-NMR shifts for methylene groups adjacent to boron in organoborane complexes useful in the invention appear below about δ0.5. The ¹H-NMR shift for methylene groups adjacent to boron is about δ1.2 for triethylborane itself. The composition prepared in Example 2 was tested using ¹H-NMR spectroscopy, with the result indicated in

10 Table 3.

Table 3

Ex.	Complexing Agent	¹ H-NMR Shift of B-CH ₂
2	sodium methoxide	0.10

15 Bonding Composition Preparation

Example 4

Initiator Component

20 The triethylborane complex of Example 1 (1.78 grams solution) (TEB-NaOH) was dissolved in 1.55 grams CROSSLINKER CX-100. Air bubbles in the composition were allowed to rise and escape.

Polymerizable Composition

A polymerizable composition was prepared by combining 39.00 grams methyl methacrylate (MMA), 28.00 grams butyl acrylate (BA), 5.35 grams methacrylic acid (MAA), and 30.00 grams poly(MMA-co-EA). Air bubbles were removed from the composition using brief stirring under vacuum.

Bonding Composition

The polymerizable composition and initiator component were packaged in a MIXPAC SYSTEM 50 applicator, the larger cylinder of the applicator holding the polymerizable composition and the smaller cylinder holding the initiator component.

The two parts were combined by simultaneous extrusion through a 10 centimeter (4 inch) long, 17-stage static mix nozzle, Part No. MX 4-0-17-5, commercially available from ConProTec; Salem, NH. Test specimens were prepared and tested according to the Overlap Shear Bond Strength Test, except that steel wire spacers (0.2 millimeter (8 mil) diameter) were inserted into the wet adhesive between the first and second untreated test panels before clamping. Results of overlap shear testing for Example 4 are tabulated in Table 4.

Table 4

Test Panel	Overlap Shear MPa (psi)
HDPE	4.22 (612)
PP	4.03 (585)
PTFE	1.71 (248)

Example 5

Initiator Component

An initiator component was prepared combining an aqueous triethylborane complex prepared as in Example 1 (6.57 grams solution) (TEB-NaOH), 11.05 grams CX-100, 1.42 grams CAB-O-SIL TS 720, and 0.96 gram P25.

Polymerizable Composition

A polymerizable composition was prepared by heating a slurry containing 19.85 grams methyl methacrylate (MMA), 9.75 grams butyl acrylate (BA), 2.40 grams methacrylic acid (MAA), 13.50 grams BLENDEX 360, and 4.55 grams ELVACITE 2010 for three hours at 70°C. The resultant dispersion was allowed to cool and was then sheared aggressively with a saw-toothed blade of a laboratory dispersator, commercially available from Premier Mill Corporation; Reading, PA. Air bubbles were removed from the composition using brief stirring under vacuum.

The polymerizable composition and initiator component were packaged and evaluated as described in Example 4. Results from testing according to the Overlap Shear Bond Strength Test are tabulated in Table 5.

Table 5

Test Panel	Overlap Shear MPa (psi)
HDPE	5.60 (812)
PP	3.89 (564)
PTFE	1.28 (185)

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of the invention. It should be understood that this invention is not limited to the illustrative embodiments set forth herein.

What Is Claimed Is:

1. An initiator system comprising:
a complexed initiator comprising at least one of:
5 a complex of a complexing agent comprising at least one hydroxide and an initiator, and
a complex of a complexing agent comprising at least one alkoxide and an initiator; and
a decomplexer.
10
2. The initiator system of claim 1, wherein the initiator comprises an organometallic initiator.
3. The initiator system of claim 1, wherein the initiator comprises an
15 organoborane initiator.
4. The initiator system of claim 1, wherein the complexed initiator comprises a complex of a complexing agent comprising at least one hydroxide and an initiator.
- 20 5. The initiator system of claim 1, wherein the complexed initiator comprises a complex of a complexing agent comprising at least one alkoxide and an initiator.
6. The initiator system of claim 1, wherein the complexed initiator comprises a complexing agent represented by Formula (II):
25
$$(\text{}^{\ominus}\text{O}-\text{R}^{\ominus})_n \text{M}^{(m+)}$$

(II)

wherein:
R[⊖] is independently selected from hydrogen or an organic group;
M^(m+) represents a countercation;
30 n is an integer greater than zero; and

m is an integer greater than zero.

7. The initiator system of claim 6, wherein n and m are equal.
- 5 8. The initiator system of claim 6, wherein each R⁴ is independently an alkyl or alkylene group.
9. The initiator system of claim 6, wherein each R⁴ is hydrogen.
- 10 10. The initiator system of claim 6, wherein M^(m+) comprises a monovalent cation.
11. The initiator system of claim 10, wherein M^(m+) comprises an onium.
- 15 12. The initiator system of claim 6, wherein M^(m+) is selected from cations of sodium, potassium, tetraalkylammoniums, and combinations thereof.
13. A kit comprising:
 - a polymerizable composition, wherein the polymerizable composition
 - 20 comprises:
 - at least one polymerizable monomer, and
 - at least one decomplexer; and
 - an initiator component, wherein the initiator component comprises:
 - a complexed initiator comprising at least one of:
 - 25 a complex of a complexing agent comprising at least one hydroxide and an initiator, and
 - a complex of a complexing agent comprising at least one alkoxide and an initiator, and
 - an optional diluent.
- 30

14. A bonding composition comprising the polymerizable composition of the kit of claim 13 mixed with the respective initiator component of the kit of claim 13.
15. A substrate at least partially coated with the bonding composition of claim 14.
16. The substrate of claim 15, wherein the substrate comprises a low surface energy substrate.
17. A bonded article comprising:
a first substrate,
a second substrate, and
a polymerized bonding composition of claim 14 that adhesively bonds the first and second substrates together.
18. A method of initiating polymerization of at least one monomer, the method comprising the steps of:
providing at least one monomer,
blending the at least one monomer with the initiator system of claim 1, and
initiating polymerization of the at least one monomer.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/04912

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 C08F4/00 C09J4/00 C09D4/00 C08F220/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 IPC 7 C08F C09J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE COMPENDEX 'Online! ENGINEERING INFORMATION, INC., NEW YORK, NY, US VLCEK P ET AL: "Anionic polymerization of acrylates. II. Polymerization of 2-ethylhexyl acrylate initiated by butyllithium/lithium-tert-butoxide system in tetrahydrofuran and its mixtures with toluene" Database accession no. EIX92091312145 XP002139167 abstract & J POLYM SCI PART A; JOURNAL OF POLYMER SCIENCE, PART A: POLYMER CHEMISTRY JUL 1992, vol. 30, no. 8, July 1992 (1992-07), pages 1511-1518, --- -/--	1,2

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents:

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Name and mailing address of the ISA
 European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
 Fax: (+31-70) 340-3018

Authorized officer

Pollio, M

INTERNATIONAL SEARCH REPORT

International Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 97 07171 A (MINNESOTA MINING & MFG) 27 February 1997 (1997-02-27) cited in the application the whole document	1-18
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